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FIFTH ANNUAL REPORT FOR:

TRAINING SPATIAL KNOWLEDGE ACQUISITION USING VIRTUAL ENVIRONMENTS

(1 February 2000 to 31 January 2001)

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1 Executive Summary

This report summarizes the work done by MIT in Year 5 (1 February 2000 through 31 January 2001) of the ONR Grant N00014-96-1-0937 entitled "Training Spatial Knowledge Acquisition Using Virtual Environments". It has been prepared by Nathaniel Durlach (PI), Dr Thomas E. v. Wiegand, Andrew Brooks, Lorraine Delhorne and Jonathan Pfautz.

Much of our effort during this period has been directed towards further refinement and development of the generic spatial-training simulation incorporating the World In Miniature (WIM), and the construction of a photorealistic model of a building at MIT for use in experiments involving this simulation. As part of this development, the entire simulation was rewritten in order to achieve compatibility with simulations in development at other ONR-funded institutions. Several improvements were made to deal with fidelity and operator interface considerations.

The second major focus of our attention has been a program of basic research into mental factors that may affect the acquisition of spatial knowledge. Experiments were performed investigating the relationship between imagined translations and imagined rotations, following results reported elsewhere in the literature. These results have implications for the structure of coordinate space in egocentric mental representations.

A white paper, "Virtual Environments and the Enhancement of Spatial Behaviour" (Durlach et al., 2000) was published in the journal Presence during this reporting period. This paper outlines a general research and development program in the area of VE-assisted spatial training in collaboration with other researchers outside MIT.

A paper detailing the Automated VE Generation System created in previous years of this grant was accepted for publication in Presence and is currently in press.

In addition, with the assistance of undergraduate research assistants, in the last year we began investigating three-dimensional textural enhancements for the Automated VE Generation System, as well as model optimizations for enhanced computational performance on automatically generated virtual models.

The body of this report contains more detailed descriptions of the improved spatial-training simulation and an introduction to the mental transformation research.

2 Spatial-Training Simulation

In order to investigate factors underlying the transfer of training of configurational knowledge to the real world, we have been developing a spatial-training simulation to facilitate testing and evaluation of supernormal VE training aids. The system places trainees inside a photorealistic model of a real-world space, such that they may be trained by free exploration, guided flythrough or some form of specific task, assisted by virtual training aids. At present the primary training aid is a device known as a World In Miniature, or WIM. The WIM is a complete 3D miniature representation of the immersive space, which appears to be held in the trainee's hand in the VE. This is accomplished by means of a 6 degree-of-freedom motion tracker that the trainee holds in his or her hand in the real world. Trainees are able to view their own position in the environment by referencing their miniature avatar in the WIM, and can remove occluding detail from the WIM with the use of a self-guided planar cutter held in the other hand, known as the "saw".

The preliminary WIM simulation that we developed in Year 4 was implemented in a collaborative shared 3D environment named DIVE. However, partly due to this environment's reliance on interpreted scripting languages, and partly due to the different optimizations chosen in the automatically generated 3D models from our Automated VE Generation System, we encountered severe performance difficulties when attempting to use our photorealistic models. These difficulties, in conjunction with our desire to standardise equipment and software with other ONR-funded research groups, led us to abandon the collaborative environment of DIVE in favour of a high-performance commercial single-user simulation environment named Vega, based on a port of Silicon Graphics' Performer. A significant part of the early effort in this reporting period involved rewriting the entire spatial-training simulation in Vega. This resulted in greatly increased rendering performance and enhanced programming capabilities, as well as enhancing our ability to share our work with other groups.

During and after the recoding effort, a number of enhancements were made to the WIM simulation. For example, the saw was modified in several ways. In the initial WIM simulation, the saw would remove any complete polygon with which it came into contact. However, this proved confusing, particularly in the case of large polygons such as ceilings and floors, as users would find the saw removing model components quite spatially distant from the plane of the saw. The saw was thus upgraded to operate at the pixel rather than the polygon level. In addition, allowing the saw to rotate through three unconstrained degrees of freedom proved challenging for novice users, so a saw access mode was added to lock the saw angles to multiples of 45 degrees, thus making it easier for trainees to generate "standard" cuts. Similarly, once a desired cut is achieved it is difficult to move both WIM and saw in concert to preserve the model view while adjusting the viewpoint, so an option to lock the saw to the WIM was also designed.

In addition to the simulation engine, a critical component of the spatial-training system is a realistic virtual model of a real world space that is also available in which to train spatial
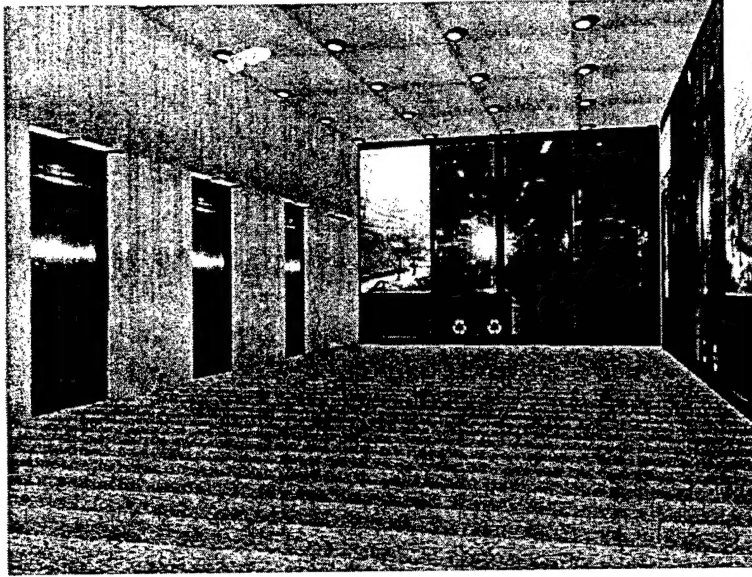
Figure 1: Example view inside photorealistic building model

knowledge, in order to evaluate training transfer. We therefore commenced construction of a photorealistic model of the basement, mezzanine and first floor of the building in which our laboratory resides. An example screenshot, showing the photographic detail, is presented in Figure 1. We anticipate that the level of detail present in this model will be sufficient to instil a sense of presence in trainees, as well as provide them with accurate cues to underpin the transfer of training to the real world for testing purposes.

3   Mental Transformation Research

We have initiated a program of basic research concerned with characterizing and modeling human performance in the exercise of basic spatial skills and abilities (BSSAs). Of particular interest is the difficulty many individuals have imagining the effects of translation and rotation.

In this study, blindfolded subjects pointed to objects after imagined movements. The imagined movements consisted of translational and rotational components. That is, the subjects *imagined* (they did not actually move) that they moved away from their original location (translation) or that they changed the direction (rotation) they were facing. Three objects (a cube, a cone, and a ball) were placed in a room at three different angles from the subject according to one of two floor plans, A or B. The subject stood behind a circular pointer that was mounted on top of a dial marked with degree gradations along the perimeter. He or she was instructed to survey the floor plan and placement of objects and was then blindfolded. The experimenter instructed the subjects with the imagined movement instructions. For each of six imaginary positions under each condition (translation or rotation), the subjects were instructed to point to the location of one of three objects (i.e., the target for the particular trial). The experimental set-up is shown in Figure 2, where the

top panels represent the floor plans for the translation portion of the experiment and the lower panels represent the floor plans for the rotation portion of the experiment. Within each floor plan the 3 basic shapes represent the 3 objects/targets, the marked circles mark the position where the subject stood during the experiment, and the circles with numbers within (translation) or beside (rotation) them represent the imagined positions of the subject following the instructions. Both response time and accuracy of response were measured for all tests. Thirty-one subjects have been tested and we are in the process of analyzing the data and writing a report.

In a second related experiment translation and rotation effects were examined using a simulated room design rather than placement of the subject in an actual room. In the simulated design, the subject was presented with a $34'' \times 22''$ piece of cardboard with a floor plan for the placement of each of the three objects (the floor plans were the same as in the real room experiment). In this room simulation, a small doll figure represented the subject's position. The circular pointer used for responses was mounted on top of the doll's head. From this point on the experiment proceeded as described above, using 10 subjects who were a subset of the original thirty-one. While the data analysis is not yet complete, a preliminary summary suggests that the subjects experienced difficulty in both translation and rotation under the real room and simulated room conditions.
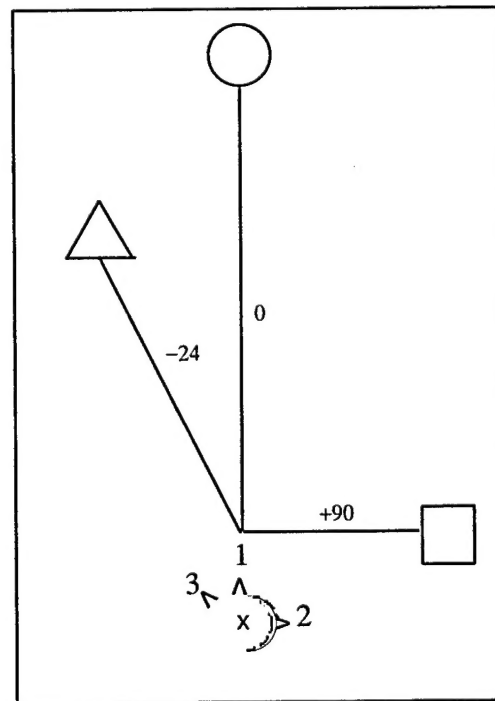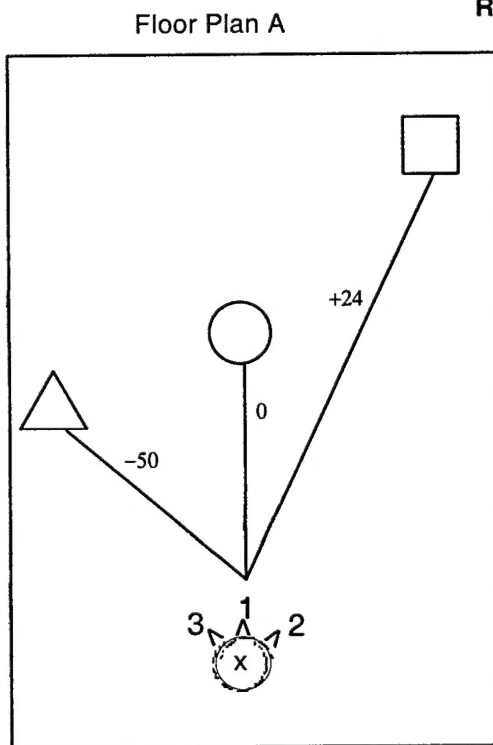
TRANSLATION

Floor Plan A

Floor Plan B

ROTATION

Floor Plan A

Floor Plan B
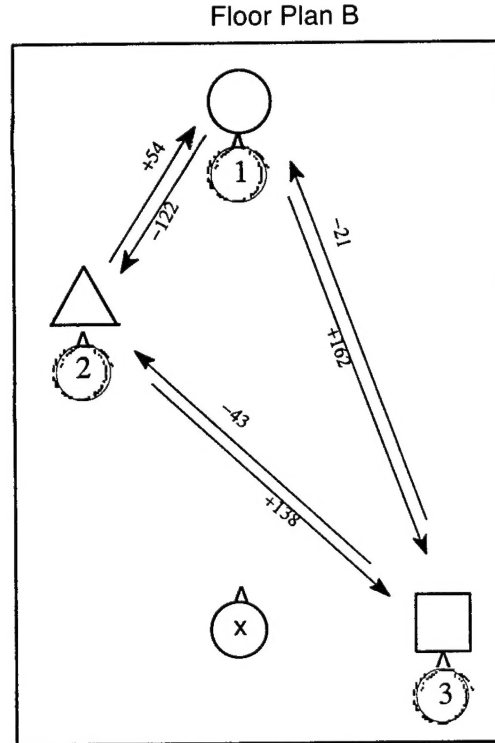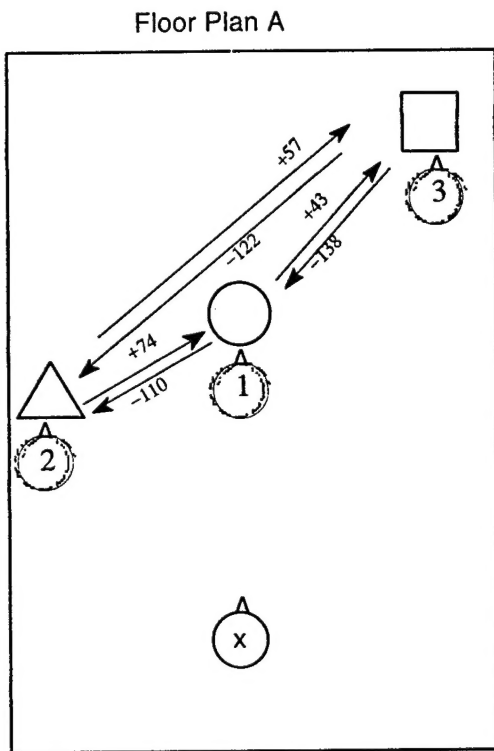
Figure 2: Diagram of experimental setup

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